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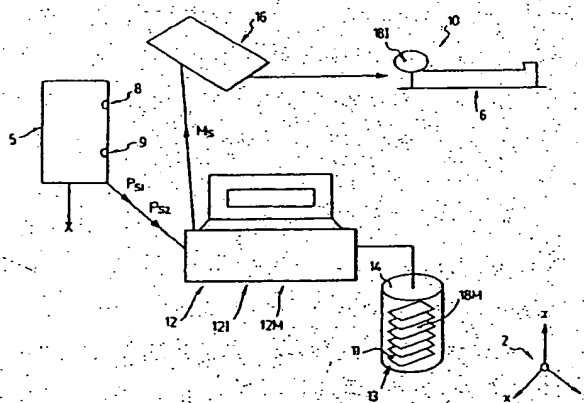


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- (71) Applicant and (72) Inventor: GLOSSOP, Neil, David [CA/CA]; 44 St. Joseph Street, Suite 806, Toronto, Ontario M4Y 2W4 (CA). For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: METHOD AND SYSTEM TO FACILITATE IMAGE GUIDED SURGERY



(57) Abstract: A method and system to facilitate image guided surgery by projecting onto the patient an image corresponding to markings made on pre-acquired images of the patient is disclosed. The image is projected by an imaging projecting device such as a laser which emits coherent visible light. The position of the patient and the image are determined in the same frame of reference. The markings made on the pre-acquired images are then mapped onto the corresponding locations of the patient. The image projecting device then projects images onto the patient corresponding to the markings made on the pre-acquired images. The images projected by the image projecting device can be temporarily or permanently marked onto the patient so that they are visible after the image projecting device stops emitting radiation. Use of aphotodynamic substance can also be used in conjunction with the light emitted from the laser to treat tumors and other abnormalities in the patient.

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METHOD AND SYSTEM TO FACILITATE IMAGE GUIDED SURGERY

FIELD OF THE INVENTION

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This invention relates generally to image guided surgery. More specifically, the present invention relates to a method and system which facilitates use of pre-acquired images of an anatomical body to pre-plan and perform medical procedures.

BACKGROUND OF THE INVENTION

15 In recent years, image guided surgery has become more and more common, in part because of the ability of a surgeon to view internal images of a patient's anatomy and pre-plan a medical operation. In this way, pre-acquired images of the anatomical body are used to plan the course of the medical procedure, whether the
20 medical procedure is diagnostic, therapeutic or surgical in nature. The pre-acquired images can also be used, to some extent, during the medical procedure for orientation of the surgeon with respect to the internal anatomy of the patient.

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The images of a patient's external or internal anatomy used in image guided surgery can be generated by a number of means, including computerized tomography (CT), magnetic resonance imaging (MRI), video,
30 ultrasound and X-rays. Images may also be captured

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using angiography, single photon emission computer tomography and positron emission tomography (PET). In all cases, at least two, and generally more than two, images of the patient's internal anatomy are generated.

- 5 The images are captured such that the relative position of the images is known. The images, along with information indicating the relative position of the images, can then be stored in a data-base to essentially create a data-base body comprised of the
- 10 pre-acquired images and corresponding to the anatomical body of the patient at the time the images were captured.

- This data-base body of images can be used for a
- 15 number of purposes, including diagnosis or to pre-plan the medical procedure. In addition, it is known in the art to process this data-base body of pre-acquired images in order to produce images of various views, as well as three-dimensional images, based on the relative
- 20 spatial relationship of the pre-acquired images within the internal anatomical structure of the patient.

- Surgeons can pre-plan the course of a medical procedure by marking, either manually or
- 25 electronically, on the data-base body of pre-acquired images the course of the medical procedure. The markings can indicate areas of interest, objects of concern, as well as proposed cuts or drilling locations and orientations, and locations which must be
- 30 irradiated with specific types of radiation for

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diagnostic or therapeutic procedures. During the medical procedure, the surgeon can then refer to the markings on the images to assist in performing the procedure.

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Furthermore, the prior art imaging devices can project a representation of the instrument or tool being used by the surgeon onto the pre-acquired images during a medical procedure. The representation
10 corresponds to the position of the actual instrument or tool with respect to the patient. By viewing the position of the representation of the instrument or tool with respect to the data-base body of pre-acquired images, the surgeon can extrapolate the position of the
15 actual probe or instrument with respect to the internal anatomy of the patient. In addition, the surgeon can simultaneously follow the pre-planned markings on the pre-acquired images.

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However, the prior art imaging devices and methods suffer from the disadvantage that the surgeon's attention is no longer directed solely toward the patient during the surgery, but rather is also directed toward the pre-acquired images, the pre-planned
25 markings and the representations of the probes and instruments on the images. In other words, during image guided surgery, the surgeon's attention is split between the patient and the data-base image of the patient. This is often disconcerting for surgeons, and
30 in particular surgeons who are unfamiliar with image

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guided surgery, because their attention is no longer solely directed toward the patient, as is the case with other types of surgery. Rather, the surgeons must view the image of the patient and the representation of the probes and instruments with respect to the data-base image while manipulating the actual probes and instruments within the patient. This can adversely affect the surgeon's hand-eye co-ordination and could result in the surgeon becoming disoriented.

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Also, because the attention of surgeons during image guided surgery is split between the patient and the image of the patient, there is a risk that a surgeon will not notice that the surgeon has stuck, or will strike, a "critical structure" within the patient. Critical structures include an organ or blood vessel, which, if struck, can critically or severely damage the patient. This is compounded by the fact that several imaging techniques do not provide detailed images of critical structures, such as organs or blood vessels, and a surgeon may not immediately see them if the surgeon's attention is directed towards the pre-acquired images rather than at the patient.

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A further disadvantage of the prior art imaging systems is that all pre-planned markings made by the surgeon are located on the pre-acquired images. Accordingly, in order to use the pre-planned markings, the surgeon must constantly refer to the images and orient the images and pre-planned markings to the

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anatomical body during the course of the medical procedure.

SUMMARY OF THE INVENTION

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Accordingly, it is an object of this invention to at least partially overcome the disadvantages of the prior art. Also, it is an object of this invention to provide a method and system to facilitate image guided surgery by projecting onto the anatomical body during the medical procedure any markings made onto the data-base body of pre-acquired images.

Accordingly, in one of its aspects, this invention resides in a system for projecting onto an anatomical body markings made on a data-base body of pre-acquired images of the anatomical body, said system comprising: a spatial determinator for determining spatial positional information of the anatomical body and generating first positional signals indicative of the spatial positional information of the anatomical body in the frame of reference; a mapping unit for receiving first positional signals indicative of the spatial positional information of the anatomical body in the frame of reference, mapping the markings made on the data-base body of pre-acquired images onto corresponding locations on the anatomical body and generating a mapping signal indicative of the corresponding locations in the frame of reference of the markings on the data-base body; and an image

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projecting device for receiving the mapping signal and projecting an image of the markings made on the data-base body onto the corresponding locations of the anatomical body.

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In a further aspect, the present invention resides in a method for projecting onto an anatomical body markings made on a data-base body of pre-acquired images of the anatomical body, said method comprising the steps of: obtaining spatial positional information of the anatomical body in a frame of reference; mapping the markings made on the data-base body of pre-acquired images onto the corresponding locations on the anatomical body; and projecting an image of the markings made on the data-base body onto the corresponding locations of the anatomical body in the frame of reference.

One of the advantages of the present invention is that an image corresponding to the markings made by the surgeon onto the data-base body of pre-acquired images can be viewed during the surgical procedure directly on the patient. In other words, the surgeon will have the benefit of any markings made on the pre-acquired images during pre-planning of the medical procedure while the surgeon's attention is directed to the patient. This permits the surgeon to more easily perform the medical procedure in a manner that the surgeon is accustomed to, rather than by watching the pre-acquired images and a representation of the instruments on the images.

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A further advantage of the present invention is that the attention of the surgeon will be directed towards the patient for greater periods of time during the medical procedure. This will assist in the surgeon identifying critical structures, which may or may not have appeared in the pre-acquired images, before they are struck. Also, even if the critical structures have appeared on the pre-acquired images, the internal anatomy of the patient may have changed since the pre-acquired images were captured. For example, the internal organs or veins of a patient could have moved, either by movement of the patient, the actual incision by the surgeon, or other means. Clearly, these movements will not be reflected in the pre-acquired images as the movements occurred after the pre-acquired images were captured and the surgeon will only notice the changes by viewing the patient.

Another advantage of the present invention is that a surgical procedure can be planned by a surgeon located in a remote location of the patient, and, with only the benefit of the pre-acquired images. For instance, the markings made on the pre-acquired images by the surgeon at the remote location will be projected onto the patient to assist the surgeon located proximate to the patient in performing the medical procedure. In addition, both surgeons can continue to mark the pre-acquired images in order to mutually identify the organs in the patient and the

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corresponding images of the organs in the pre-acquired images. In this way, telesurgery can be facilitated.

Another advantage of the present invention is that
5 the images projected by the image projecting device can be marked, either temporarily or permanently, onto the patient. This can be performed by having an image projecting device which emits radiation that can permanently mark a patient, such as by use of a CO₂
10 laser which could burn the image onto the anatomy of the patient, either on the skin or on the bone.

Likewise, use of a photoreactive ink which perceptively changes in response to radiation emitted by the image projecting device can be used to temporarily mark the
15 patient with markings made to the pre-acquired images.

In a similar manner, use of an ultraviolet laser could be used to leave a mark on the skin of the patient corresponding to markings made to the pre-acquired images. In this way, a surgeon can quickly and
20 accurately mark onto the patient any markings made onto the images during pre-planning.

In another aspect of the present invention, the markings on the pre-acquired images can correspond to
25 areas or tumours which must be irradiated as part of a photodynamic therapeutic procedure. In other words, substances which can change cells of the patient, such as photodynamic agents which react to specific types of radiation to become cytotoxic, can be applied to the
30 patient. The image projecting device can be programmed

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to emit the types of radiation to which the photodynamic agent reacts. In this way, portions of the patient, such as tumours, can be eliminated or destroyed in a precise and predetermined manner by irradiating the patient with the specific type of radiation in a pre-planned manner. Also, because the radiation will be applied in a specific and pre-planned manner, a higher level of accuracy can be obtained for irradiating the patient, and therefore a more general photodynamic agent can be used which may be partially absorbed by the healthy tissue, as only the tumours will be irradiated. Likewise, a more intense beam of light can be used because it is less likely that healthy tissues will be irradiated.

Another advantage of the present invention is that the image projecting device can emit radiation to cauterize an area of the body. In this way, the area of the patient which is to be cauterized, such as the portion of the brain around a tumour that is to be removed, can be pre-planned and executed automatically once the tumour has been removed.

Further aspects of the invention will become apparent upon reading the following detailed description and drawings which illustrate the invention and preferred embodiments of the invention.

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BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, which illustrate embodiments of the invention:

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Figure 1 shows a symbolic representation of a system according to one embodiment of the present invention;

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Figure 2 is a further symbolic representation of a system according to one embodiment of the present invention to project an image;

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Figure 3 is a symbolic representation of a system according to one embodiment of the present invention used to guide a drill; and

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Figure 4 is a symbolic representation of a system according to one embodiment of the present invention used to diagnose or treat a patient.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 illustrates the system, shown generally by reference numeral 10, according to one embodiment of the present invention. As shown in Figure 1, the system 10 comprises a spatial determinator 5 which can determine spatial positional information for various objects in the frame of reference 2. The frame of reference 2, which is shown symbolically by the xyz

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origin, is generally the frame of reference 2 within which the patient 6 is located.

The spatial determinator 5 can be any type of device which can determine the spatial position of objects in the frame of reference 2. However, in a preferred embodiment, the spatial determinator 5 comprises an optical tracking system which utilizes two cameras 8 and 9 to track the position and orientation of objects in the frame of reference 2 and send position signals P_s indicative of the spatial positional information of the objects being tracked in the frame of reference 2. It is understood that the spatial positional information may include information regarding the position, as well as the orientation, of the object in the frame of reference 2.

One object which the spatial determinator 5 tracks in the frame of reference 2 is an anatomical body which, in the embodiment shown in Figure 1, corresponds to the patient 6. The spatial determinator 5 will determine the spatial position of the patient 6 and generate first positional signals P_{s1} indicative of the spatial positional information of the anatomical body 6 in the frame of reference 2.

The first positional signals P_{s1} are received by a mapping unit 12M which, in the embodiment shown in the Figure 1, is contained in a computer 12. It is understood that the mapping unit 12M can be contained

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within any physical structure which can execute the functions of the mapping unit 12M and the computer 12 shown in Figure 1 is simply presented as a representation of one possible physical structure within which the mapping unit 12M may be contained.

The mapping unit 12M is connected to a storage unit 14 within which pre-acquired images 11 of the anatomical body 6 are stored. The pre-acquired images 11 stored within the storage unit 14 can form a data-base body 13 of the patient 6, as is known in the art. The storage unit 14 can comprise any type of storage medium to store the data-base body 13 of pre-acquired images 11 for use by the mapping unit 12M.

In addition to the data-base body 13 of pre-acquired images 11, the storage unit 14 will also have stored thereon any markings, shown generally by reference numeral 18M, made on the data-base body 13. In other words, if a surgeon or other person has made markings 18M on the data-base body 13, these markings will be stored in the storage unit 14 and can be accessed by the mapping unit 12M. The markings 18M may be stored either with the images 11 or separately with an indication of how the markings 18M relate to the data-base body 13 of pre-acquired images 11.

The mapping unit 12M receives the first positional signal P_{S1} from the spatial determinator 5 indicating the spatial positional information of the anatomical

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body 6 in the frame of reference 2. The mapping unit 12M then maps the markings 18M made on the data-base body 13 of pre-acquired images 11 onto corresponding locations of the anatomical body 6. In order to
5 accomplish this, a registration procedure, as is known in the art, will generally be performed to register key features on the anatomical body 6 to corresponding key features on the data-base body 13.

10 The mapping unit 12M will then generate a mapping signal M_s indicative of the corresponding locations in the frame of reference 2 of the markings 18M made on the data-base body 13. In other words, the mapping
15 signal M_s will comprise the xyz positional information of the corresponding locations in the frame of reference 2, and likely on the anatomical body 6, of the markings 18M made on the data-base body 13. In cases where the orientation of the markings 18M is
20 relevant, the mapping signal M_s will also comprise the information regarding the orientation of the markings 18M in the frame of reference 2. The mapping signal M_s is then received by an image projecting device 16. The
25 image projecting device 16 can comprise a laser or other image projecting device 16 which can project an image onto any position in the frame of reference 2.

The image projecting device 16 projects an image, shown generally by reference numeral 18I, based on the mapping signal M_s . The image 18I corresponds to the
30 markings 18M made on the data-base body 13, but

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projected onto the corresponding locations of the anatomical body 6 in the frame of reference 2. For example, if a surgeon had marked the pre-acquired images 11 with a marking 18M indicating the incision to be made, the image 18I will correspond to the location on the anatomical body 6 where the marking 18M for the incision was made on the data-base body 13.

In a preferred embodiment, the image projecting device 16 projects the image 18I in a manner which can be tracked by the spatial determinator 5. In this way, the spatial determinator 5 can track the image 18I and determine the spatial information for the image 18I in the frame of reference 2. The spatial determinator 5 can then generate a second positional signal P_{s2} indicative of the spatial positional information of the image 18I in the frame of reference 2. The mapping unit 12M receives the second positional signal P_{s2} in addition to the first positional signal P_{s1} and can determine whether or not the image 18I being projected by the image projecting device 16 corresponds to the position of the markings 18M made on the data-base body 13 of pre-acquired images 11. If the mapping unit 12M detects a disparity between the actual location of the image 18I being projected and the intended location of the projection, the mapping unit 12M can send a modified mapping signal M_s to correct the disparity and project a more accurate image 18I.

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Preferably, the image projecting device 16 can project the image by emitting radiation which is perceptible by the spatial determinator 5. For example, if the spatial determinator 5 comprises an optical tracking system having cameras 8 and 9, the cameras 8 and 9 can sense or perceive the radiation being emitted by the image projecting device 16, and thereby generate the second positional signal P_{s2} indicative of the spatial positional information of the image 18I in the frame of reference 2.

If the cameras 8 and 9 of the optical tracking system cannot track visible radiation, it will be necessary for the image projecting device 16 to first project the image 18 by emitting radiation which is perceptible to the cameras 8, 9. Once the mapping unit 12M has determined that the image 18I being projected corresponds to the markings 18M made on the data-base body, the projecting device 16 will then emit radiation which is visually perceptible, or otherwise visually mark the image 18 onto the anatomical body 6. In a preferred embodiment, the projecting device 16 can be configured to project a laser beam 22 having two different frequencies, one of which is perceptible to the cameras 8, 9 and the other which is visually perceptible. This may include, for example, temporally interleaving, multiplexing or temporally overlapping the image 18I projected in the emitted radiation which is perceptible to the cameras 8, 9 and, the emitted radiation which is visually perceptible. This can be

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co-ordinated so that the projecting device 16 projects the image 18I by emitting radiating radiation which is perceptible to the cameras 8, 9 for a period of time sufficient for the spatial determinator 5 to determine the position of the projected image 18I and then emitting radiation which is visually perceptible. Should the spatial determinator 5 not require a great deal of time to sense or perceive the radiation being emitted by the image projecting device 16, there may not be a great degradation in the visually perceptible image 18I since the visually perceptible image 18I can be updated sufficiently rapidly.

Preferably, the computer 12 also comprises an input unit 12I for inputting information, including instructions and data. For example, the inputting unit 12I can be used to input additional markings 18M onto the data-base body 13. In this way, a surgeon can continuously make markings 18M on the data-base body 13 during the procedure. The projecting device 16 can then project images 18I of the markings 18M, including the markings made through the input unit 12I, onto the patient 6.

In addition, if several markings 18M are made on the data-base body 13 of pre-acquired images 11, the input unit 12I can be used to input information comprising instructions as to which marking 18M the image projecting device 16 should be projecting. For example, during a surgical procedure, the surgeon may

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have marked onto the data-base body 13 markings 18M reflecting the incision, the position and orientation of an entry point, as well as internal features of the patient 6 which should be treated. Accordingly, the input unit 12I can be used by the surgeon to input instructions as to which markings 18M should be projected during different stages of the surgical procedure. In addition, if the projecting device 16 can project two different images 18I simultaneously, such as if the projecting device 16 emits a first coherent beam of visible light and a second coherent beam of visible light, the surgeon can use the input unit 12I to select not only which markings 18M are being projected, but also which coherent beam of light is being used to project the corresponding images 18I. This is particularly useful if the image projecting device 16 emits a second coherent beam of visible light which is of a different wavelength, and therefore different colour, than the first coherent beam of visible light, so that the surgeon can easily distinguish between the two images 18I being projected.

It is also understood that the input unit 12I need not be located proximate the computer 12. In other words, a surgeon located remote from the second frame of reference 2 can have an input unit 12I and send information, including instructions as to additional markings 18M and a selection of the markings 18M to be projected to the computer 12. In this way, telesurgery can be facilitated by the surgeon located proximate the

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patient 6 immediately seeing the projection of the image 18I, the markings 18M being made and selected by a remotely located surgeon. This facilitates image guided surgery by permitting a remotely located surgeon to guide the proximately located surgeon through the procedure by projecting images 18I of the marking 18M made by the remotely located surgeon directly onto the patient 6.

Likewise, if two surgeons are located proximate the patient 6, both surgeons can also use the input unit 12I to non-obtrusively identify portions of the patient's 6 anatomy by marking the portion on the database body 13 and then having the image projecting device 16 project the image 18I corresponding to the markings 18M. This could also be used by instructors to identify items of interest in a non-evasive manner by projecting the image 18I onto the items of interest, rather than touching the actual items of interest.

It is understood that the input unit 12I can comprise any type of means for inputting information. For example, the input unit 12I can comprise a keyboard or a mouse. The input unit 12I can also be voice-activated such that a surgeon can send verbal commands to the input unit 12I as to which markings 18M should be projected.

Figure 2 shows a further embodiment of the present invention. In Figure 2, the image projecting device 16

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comprises a laser which emits a coherent beam of visible light, such as laser beam 22. It is understood that the image projecting device 16 may be calibrated or otherwise registered so that it could direct the laser beam 22 to a known position in the frame of reference 2 in response to the mapping signals M_s . In order to assist in directing the laser beam 22, the image projecting device 16 can comprise translation devices 16T which can move the image projecting device 16 such that the laser beam 22 will have the proper position and, if desired, orientation.

In a preferred embodiment, the spatial determinator 5 tracks the position of the image projecting device 16. This may assist in calibrating or registering the image projecting device 16 in the frame of reference 2. Also, if the image projecting device 16 comprises translation devices 16T, the spatial determinator 5 can track the position of the image projecting device 16 and send a signal (not shown) to the mapping unit 12M indicative of the position of the image projecting device 16 in the frame of reference 2. The mapping unit 12M can then determine whether or not the image projecting device 16 has been moved by the translation devices 16T to the correct position to project image 18I of the markings 18M made on the data-base body 13 onto the corresponding locations or the anatomical body 6 in the frame of reference 2.

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As also illustrated in Figure 2, it is preferred that the spatial determinator 5 be located proximate the image projecting device 16 in the frame of reference 2. In this way, it will be possible for the spatial determinator 5 to easily track the image 18I being produced by the laser beam 22. Also, it is desirable to have the spatial determinator 5 and the image projecting device 16 proximate to each other and out of the way from the surgeons and other medical equipment. In this regard, it is preferable that both the spatial determinator 5 and the image projecting device 16 be located in otherwise unused space, such as near the ceiling of the operating room.

The patient 6 in Figure 2 is positioned on a table, such as an operating table 20. As shown in Figure 2, the image projecting device 16 will project the image 18I onto the patient 6.

If the image 18I comprises a circle or other two-dimensional representation, the image projecting device 16 can quickly move the laser beam 22 to produce the image 18I. The laser beam 22 can be moved rapidly by the image projecting device 16 so that the viewer will perceive a substantially continuous image 18, represented by the dotted line on the patient 6 in Figure 2, by the persistence of vision effect. If desired, fluorescence or other methods could also be used. It is understood that as the surface upon which the image 18I will be projected will be the surface of

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an anatomical feature of the patient 6, and therefore not necessarily flat, the projecting device 16 and the mapping unit 12M will compensate for the shape of the anatomical feature of the patient 6 so that image 18I of the markings 18M made on the data-base body 13 appear on the corresponding locations of the anatomical body of the patient 6 even though the surface is not flat.

10 In addition, the laser beam 22 could be configured such that it can permanently mark the image 18I onto the patient 6. This can be accomplished, for example, by using an image projecting device 16 which emits a laser beam 22 that can permanently mark the patient 6.
15 For example, use of a projecting device 16 which comprises a CO₂ or ultraviolet laser could "burn" the image 18I onto the anatomy, such as either on the skin or on the bone, of the patient 6. In this way, once the image 18I has been "burned" or otherwise
20 permanently marked on the patient 6, the image projecting device 16 can then cease projecting the image 18I and discontinue emitting the laser beam 22.

In a preferred embodiment, use of photoreactive ink, shown generally by reference numeral 28 in Figure 2, can be applied to the patient 6. The photoreactive ink 28 would preferably react to the radiation emitted by the image projecting device 16, such as the laser beam 22, and change in a visually perceptible manner in
25 response to the laser beam 22. In this way, the image
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18I projected by the image projecting device 16 would be temporarily or permanently marked onto the patient 6 by means of the photoreactive ink perceptively changing in response to the emitted radiation. Accordingly, in this way, the markings 18M made on the data-base body 13 can be easily transferred to temporary or permanent markings on the patient 6 by means of the projected image 18I. In this case, it is understood that radiation emitted by the image projecting device 16 need not be visually perceptible, but only cause the photoreactive ink 28 to react in a perceptible manner.

Figure 2 also shows a tracking tool 24 attached to the patient 6 by means of a support 25. The tracking tool 24 can assist in tracking the position and orientation of the patient 6 in the frame of reference 2. In a preferred embodiment, where the spatial determinator 5 comprises an optical tracking system having cameras 8 and 9, the tracking tool 24 will have tracking emitters or reflectors 26 which can be perceived by the cameras 8, 9. In this way, the cameras 8, 9 can easily track the position of the tracking elements 26 and thereby determine the position and orientation of the patient 6 in the frame of reference 2. The tracking tool 24 can comprise any type of tracking tool, such as the tracking tool described in U.S. Patent 5,834,759 which is incorporated herein by reference.

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Figure 3 shows a further embodiment of the present invention. In Figure 3, the image projecting device 16 is projecting the laser beam 22 at an entry point 18E into the patient 6.

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It is apparent from a comparison of Figures 2 and 3 that the entry point 18E corresponds to a specific point on the image 18I shown in Figure 2. In other words, in Figure 2 the image projecting device 16 is projecting the image 18I of a first marking 18M made on the data-base body 13 which represents the portion of the skull of the patient 6 which is to be removed. In Figure 3, the image projecting device 16 is projecting the image of the entry point 18E which corresponds to the markings 18M made on the data-base body 13 indicating the desired entry point to the patient 6 in order to remove the portion of the skull represented by image 18I. The projecting device 16 could either project the image 18I or the image of the entry point 18E according to the signals inputted from the input unit 12I as discussed above. Alternatively, both the image 18I and the image of the entry point 18E could be projected at the same time.

25 In the case of the entry point 18E, a surgeon may be concerned not only with the position of the entry point 18E, but also the orientation of the entry point 18E. The markings 18M on the data-base body 13 would likely include a vector having a position, as well as an orientation, to uniquely identify the entry point in

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six degrees of freedom. Accordingly, the image of the entry point 18E will have an orientation and position which corresponds to both the position and orientation of the markings 18M made on the data-base body 13.

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As shown in Figure 3, the orientation and position of the laser beam 22, which corresponds to the markings 18M made on the data-base body 13, can be used by the surgeon to align instruments, such as drill 30, for entry into the patient 6. It is apparent that as the surgeon aligns the drill 30 by means of the laser beam 22, the surgeon will have the benefit of seeing the image of the entry point 18E corresponding to the markings 18M made on the data-base body 13, as well as be able to observe the drill 30 as it cuts into the entry point 18E of the patient 6. In this way, the surgeon will not only know that the position of the drill 30 corresponds to the markings 18M made on the data-base body 13, but the surgeon will also be able to view the drill 30 entering into the entry point 18E. This will assist the surgeon in orienting the drill 30, as well as permit the surgeon to become immediately aware of any "critical structures" which may be encountered by the drill 30, even if these "critical structures" did not appear on the pre-acquired images 11.

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The drill 30 may also be attached to a tracking tool 34, similar to the tracking tool 24 attached to the patient 6. The tracking tool 34 can comprise

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tracking elements 36 which are tracked by the cameras 8, 9 when the spatial determinator 5 comprises an optical tracking system. In this way, the drill 30 can also be tracked in the frame of reference 2 and a representation of the tool 30 may appear on the data-base body 13 of pre-acquired image 11. As such, the surgeon will have the benefit of both viewing the orientation and position of the markings 18M projected by the image projecting device 16 on the patient 6, as well as viewing a representation of the drill 30 on the data-base body 13 of pre-acquired images 11, as is done on conventional systems.

In a further preferred embodiment, the system 10 may generate an audible alarm if the position of the drill 30, as perceived by the cameras 8, 9 deviates from the orientation and position of the markings 18M as represented by the laser beam 22. In this way, the surgeon will be immediately advised if the drill 30 does not follow the path of the markings 18M made on the data-base body 13 of pre-acquired images 11.

Figure 4 shows a further embodiment of the present invention. In Figure 4, a portion of the skull of the patient 6 has been removed. It will be apparent from a comparison of Figures 2 and 4 that the hole in the skull 40 corresponds to the image 18I made by the image projecting device 16 and illustrated in Figure 2. Accordingly, the surgeon has removed a portion of the

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skull 40 as pre-planned and as projected by the image
18I onto the patient 6 as shown in Figure 2.

With the portion of the skull removed, a treatment
5 area 42 is revealed. In a preferred embodiment, the
image projecting device 16 can also be used to diagnose
and/or treat the patient 6 as follows.

As shown in Figure 4, a radiation detecting device
10 48 is present to detect radiation from the anatomical
body 6. The radiation detecting device 48 has a field
of view 46 and will detect radiation reflected from the
anatomical body 6, and more specifically the treatment
area 42 of the anatomical body 6. In this way, the
15 image projecting device 16 can project diagnostic
images 18D, and if desired, in with different types of
radiation, into the treatment area 42 corresponding to
markings 18M made on the data-base body 13. The
radiation from the diagnostic image 18D will be
20 reflected towards the field of view 46 of the radiation
detecting device 48. By using different types of
radiation, the radiation detecting device 48 will be
able to analyze the radiation detected from the
treatment area 42 of the anatomical body 6 to determine
25 characteristics of the anatomical body 6 being radiated
by the image projecting device 16. In this way,
diagnostic procedures can be performed within the
treatment area 42 based on diagnostic markings 18D and
previously made to the data-base body 13.

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It is understood that the image detecting device 48 comprises a detector 49 which detects the radiation reflected from the anatomical body 6 in field of view 46. The radiation detecting device 48 also comprises the electronics to analyze the radiation detected from the anatomical body 6 to determine the characteristic of the anatomical body being irradiated. Rather than having the electronics located proximate the detector 49, the electronics can be located in another location, and could be contained within the computer 12. Also, while the detector 49 for the radiation detecting device 48 is shown separate from the spatial determinator 5, in one embodiment where the spatial determinator 5 comprises an optical tracking system, the cameras 8, 9 of the optical tracking system may also be used as the detector 49 for the radiation detecting device 48 if the cameras 8, 9 can detect the type of radiation being reflected from the anatomical body 6.

20

Also, as shown in Figure 4, in addition to the image projecting device 16, a second separate beam source 44 which emits beam 45 could be used in addition to, or in replacement of, the image projecting device 16 and the beam 22. Of course, if the beam source 44 is to project an image 18D corresponding to the markings 18M made on the data-base body 13, it will be necessary for the beam source 44 to receive signals corresponding to the mapping signals M_s , as is done by the image projecting device 16.

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In a further preferred embodiment, the system 10 can be used to treat the patient 6. This can be done in one manner by applying a substance to the anatomical body 6 which reacts to a specific type of radiation. Preferably, the reaction would cause cells of the anatomical body 6 to which the cells of the anatomical body 6 to which the substance and radiation have been applied to change. For example, the substance can become cytotoxic and kill the cells in its vicinity in reaction to specific types of radiation. For example, the substance may comprise a photodynamic agent which is applied either to the surface of the treatment area 42, intravenously or orally by the patient 6. The photodynamic agent can be taken up non-preferentially by the healthy tissue, as well as any tumours, in the patient 6. The photodynamic agent can then react to the radiation from the laser beam 22 to change the cells of the anatomical body 6 such as by becoming cytotoxic and killing the cells in the vicinity.

Because the images 18D can be projected in a precise manner to irradiate objects in the treatment area 42, corresponding to markings 18M on the data-base body 13, more precise irradiation of the treatment area 42 can be accomplished. In this way, only the tumours within the treatment area 42 can be irradiated, thereby providing more precise photodynamic therapy. Also, because of the precision of the application of the radiation by means of the projecting device 16, more

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general photodynamic agents can be used which may be partially absorbed by the healthy tissue, as well as the tumour, because the laser beam 22 will only be directed to an image corresponding to the markings 18M on the tumour in the data-base body 13. For the same reasons, a more intense laser beam 22 could be used.

In a similar manner, an intense laser beam 22 can be used without a substance, such as a photodynamic agent, to treat the patient 6. For example, if a tumour bed has been marked on the data-base body 13, an intense beam, such as from a CO₂ laser, can be used to cauterize the tumour bed. In this way, the tumour bed, or other portion of the anatomical body 6, can be cauterized in a rapid and precise manner.

It is understood that the image detecting device 48 comprises a detector 49 that detects the radiation reflected or emitted by means of a photonic interaction from the anatomical body 6 or a debris plume 47. The second beam source 44, and if desired, a third beam source (not shown) could be used to induce a photonic reaction in the plume 47, including non-linear optical effects, Raman or fluorescent scattering or similar effects to determine partial or complete composition of the plume 47 or components thereof. Using the well-known principle of "differential absorption", it is possible to determine the chemical composition of the plume 47 by comparing the relative absorption of two closely tuned laser beams 22, 45.

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In addition, the system 10 can be used in other procedures in order to treat the patient 6. For example, tattoos or other surface blemishes may appear on pre-acquired images 11. The tattoos can be marked by markings 18M on the data-base body 13 formed by the pre-acquired images 11. The image projecting device 16 can then emit radiation which will blanch the tattoos or other surface blemishes in a rapid and precise manner corresponding to markings 18 made on the data-base body 13.

It is understood that while the present invention has been described in terms of the anatomical body 6 of the human, the system 10 and method of using the system 10 are not limited to use on humans. Rather, the system 10 and method of using the system 10 can be used in veterinary and other applications where an image of markings made on pre-acquired images must be projected onto the corresponding locations of the objects from which the images were acquired.

It is also understood that while the present invention has been described and illustrated in terms of a surgical procedure on the skull of the patient 6, the invention is not limited to this application. Rather, the invention can be used in any type of surgical procedure where projection of images corresponding to the markings 18 on pre-acquired images 11 will facilitate image guided surgery.

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It will be understood that, although various features of the invention have been described with respect to one or another of the embodiments of the invention, the various features and embodiments of the invention may be combined or used in conjunction with other features and embodiments of the invention as described and illustrated herein.

10 Although this disclosure has described and illustrated certain preferred embodiments of the invention, it is to be understood that the invention is not restricted to these particular embodiments. Rather, the invention includes all embodiments which
15 are functional, electrical or mechanical equivalents of the specific embodiments and features that have been described and illustrated herein.

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The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

- 5 1. A system for projecting onto an anatomical body markings made on a data-base body of pre-acquired images of the anatomical body, said system comprising:
 - a spatial determinator for determining spatial
 - 10 positional information of the anatomical body and generating first positional signals indicative of the spatial positional information of the anatomical body in the frame of reference;
 - a mapping unit for receiving first positional
 - 15 signals indicative of the spatial positional information of the anatomical body in the frame of reference, mapping the markings made on the data-base body of pre-acquired images onto corresponding locations on the anatomical body and generating a
 - mapping signal indicative of the corresponding
 - 20 locations in the frame of reference of the markings on the data-base body; and
 - an image projecting device for receiving the mapping signal and projecting an image of the markings made on the data-base body onto the corresponding
 - 25 locations of the anatomical body.
2. The system as defined in claim 1 wherein the image projecting device emits a coherent beam of light which can burn the anatomical body such that the image of the

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markings projected by the image projecting device will be permanently marked onto the anatomical body.

3. The system as defined in claim 1 further

5 comprising:

a substance which reacts to a specific type of radiation by changing in a perceptible manner;

wherein the image projecting device emits the type of radiation to which the substance reacts; and

10 wherein the substance can be applied to the anatomical body such that projecting the image in the type of radiation to which the substance reacts onto the anatomical body will mark the anatomical body with the image projected by the image projection device.

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4. The system as defined in claim 1 further comprising the steps of:

applying a substance to the anatomical body which reacts to a specific type of radiation by changing

20 cells of the anatomical body to which the substance has been applied; and

wherein projecting the image in the type of radiation to which the substance reacts onto the anatomical body changes the cells of a portion of the

25 anatomical body to which the substance is applied and the type of radiation is projected.

5. The system as defined in claim 1 wherein the spatial determinator comprises an optical tracking

30 system to track objects in the frame of reference; and

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wherein the optical tracking system optically tracks the anatomical body in the frame of reference and generates the first positional signals indicative of the spatial positional information of the anatomical
5 body in the frame of reference.

6. The system as defined in claim 5 wherein the image projected by the image projecting device can be tracked by the optical tracking system; and

10 wherein the optical tracking system tracks the image projected by the image projection device and generates second positional signals indicative of the spatial positional information of the image in the frame of reference; and

15 wherein the mapping unit receives the first positional signals and second positional signals and determines whether the image being projected by the image projecting device corresponds to the markings made on the data-base body of pre-acquired images.

20 7. The system as defined in claim 6 wherein if the image being projected by the image projecting device does not correspond to the markings made on the data-base body, the mapping unit regenerates the mapping
25 signal to cause the projecting device to project a more accurate image of the markings made on the data-base body.

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8. The system as defined in claim 5 wherein the optical tracking system is proximate the image projecting device in the frame of reference.

5 9. The system as defined in claim 1 further comprising:

radiation detecting device for detecting radiation from the anatomical body;

10 wherein the image projecting device projects the image of the markings made on the data-base body onto the corresponding locations of the anatomical body using types of radiation which can be reflected from the anatomical body towards the radiation detecting device; and

15 wherein the radiation detecting device analyzes the radiation detected from the anatomical body to determine a characteristic of the anatomical body being irradiated by the image projecting device.

20 10. The system as defined in claim 9 wherein the spatial determinator comprises an optical tracking system to track objects in the frame of reference;

25 wherein the optical tracking system optically tracks the anatomical body in the frame of reference and generates the first positional signals indicative of the spatial positional information of the anatomical body in the frame of reference; and

30 wherein the optical tracking system and the radiation detecting device share a common radiation detector.

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11. The system as defined in claim 1 further comprising:

5 storage unit for storing said data-base body of pre-acquired images, said storage unit being connected to the mapping unit;

an input unit connected to said storage unit for inputting information, said information comprising markings made onto the data-base body of pre-acquired
10 images;

wherein information corresponding to markings made on the data-base body of pre-acquired images can be inputted at all times; and

wherein the image projected by the image
15 projecting device can comprise the markings made on the data-base body by information inputted through the input unit.

12. The system as defined in claim 11 wherein the
20 image projecting device emits a first coherent beam of visible light; and

wherein information inputted in the input unit determines which of the markings made on the data-base body are projected by the image projecting device.

25

13. The system as defined in claim 12 wherein the image projecting device emits a second coherent beam of visible light of a different wavelength from the first coherent beam of visible light; and

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wherein the information inputted into the input unit selects which markings made on the data-base body are projected by the first coherent beam of visible light and the second coherent beam of visible light.

5

14. The system as defined in claim 1 wherein the image projecting device emits a coherent beam of visible light; and

wherein the image projected onto the anatomical body comprises a visible beam of coherent light having a position and orientation corresponding to the markings made on the data-base body of pre-acquired images.

10

15. A method for projecting onto an anatomical body markings made on a data-base body of pre-acquired images of the anatomical body, said method comprising the steps of:

obtaining spatial positional information of the anatomical body in a frame of reference;
mapping the markings made on the data-base body of pre-acquired images onto the corresponding locations on the anatomical body; and
projecting an image of the markings made on the data-base body onto the corresponding locations on the anatomical body in the frame of reference.

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16. The method as defined in claim 15 further comprising the step of:

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permanently marking the anatomical body with the image projected by the projection device.

17. The method as defined in claim 16 wherein the
5 image projecting device emits a coherent beam of light which can burn the anatomical body;

wherein the step of permanently marking the anatomical body comprises the step of projecting the image of the markings onto the anatomical body such
10 that the markings are permanently burnt thereon.

18. The method as defined in claim 15 further comprising the step of:

temporarily marking the anatomical body with the
15 image projected by the projection device.

19. The method as defined in claim 18 further comprising the steps of:

applying a substance to the anatomical body which
20 reacts to a specific type of radiation by changing in a perceptible manner; and

projecting the type of radiation to which the substance reacts onto the anatomical body corresponding to the markings made to the data-base body of pre-
25 acquired images so that the anatomical body is temporarily marked with the image projected by the image projection device.

20. The method as defined in claim 15 further
30 comprising the steps of:

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applying a substance to the anatomical body which reacts to a specific type of radiation by changing cells of the anatomical body to which the substance has been applied; and

5 wherein projecting the image in the type of radiation to which the substance reacts onto the anatomical body changes the cells of a portion of the anatomical body to which the substance is applied and the type of radiation is projected.

10 21. The method as defined in claim 15 wherein the image projecting device emits visible light; and
 wherein the step of projecting an image of the markings onto the anatomical body comprises the step of
15 projecting a visible image of the markings onto the anatomical body.

 22. The method as defined in claim 15 wherein the image projecting device emits a first coherent beam of
20 visible light; and

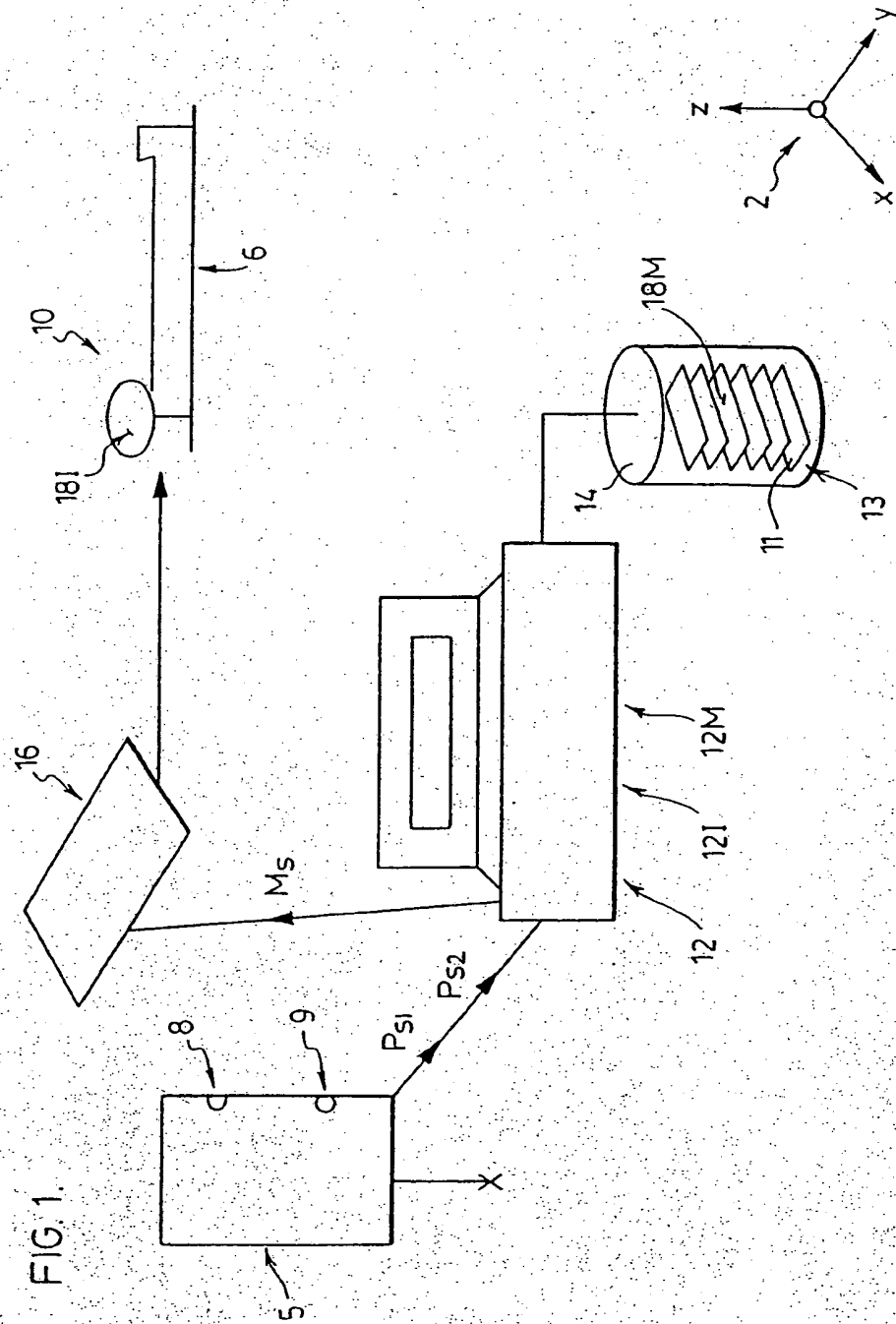
 wherein the step of projecting an image of the markings onto the anatomical body comprises the step of
projecting a visible beam of light having a position and orientation corresponding to the markings made on
25 the data-base body.

 23. The method as defined in claim 22 wherein the image projecting device emits a second coherent beam of
visible light at a different wavelength from the first
30 coherent beam of visible light; and

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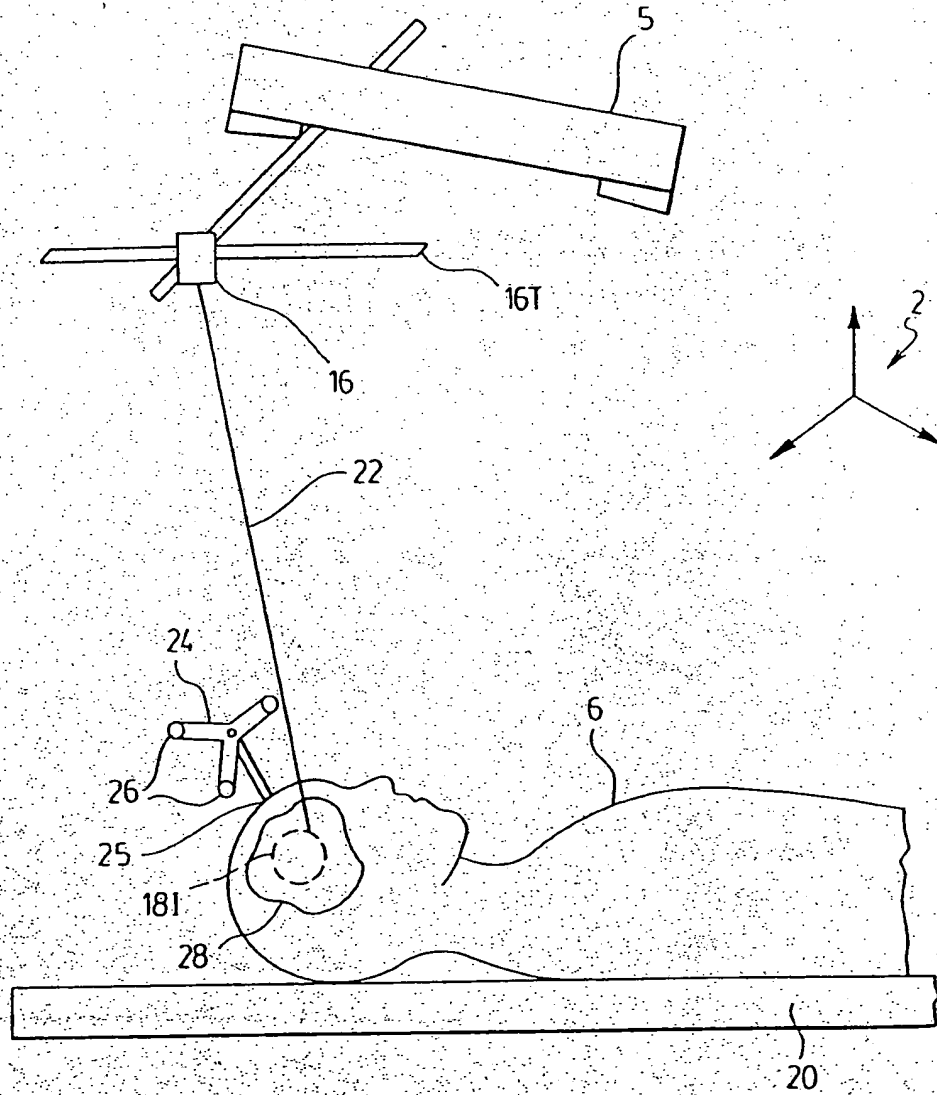
wherein the first and second coherent beams of visible light project images of different markings onto the anatomical body corresponding to the markings made on the data-base body of pre-acquired images.

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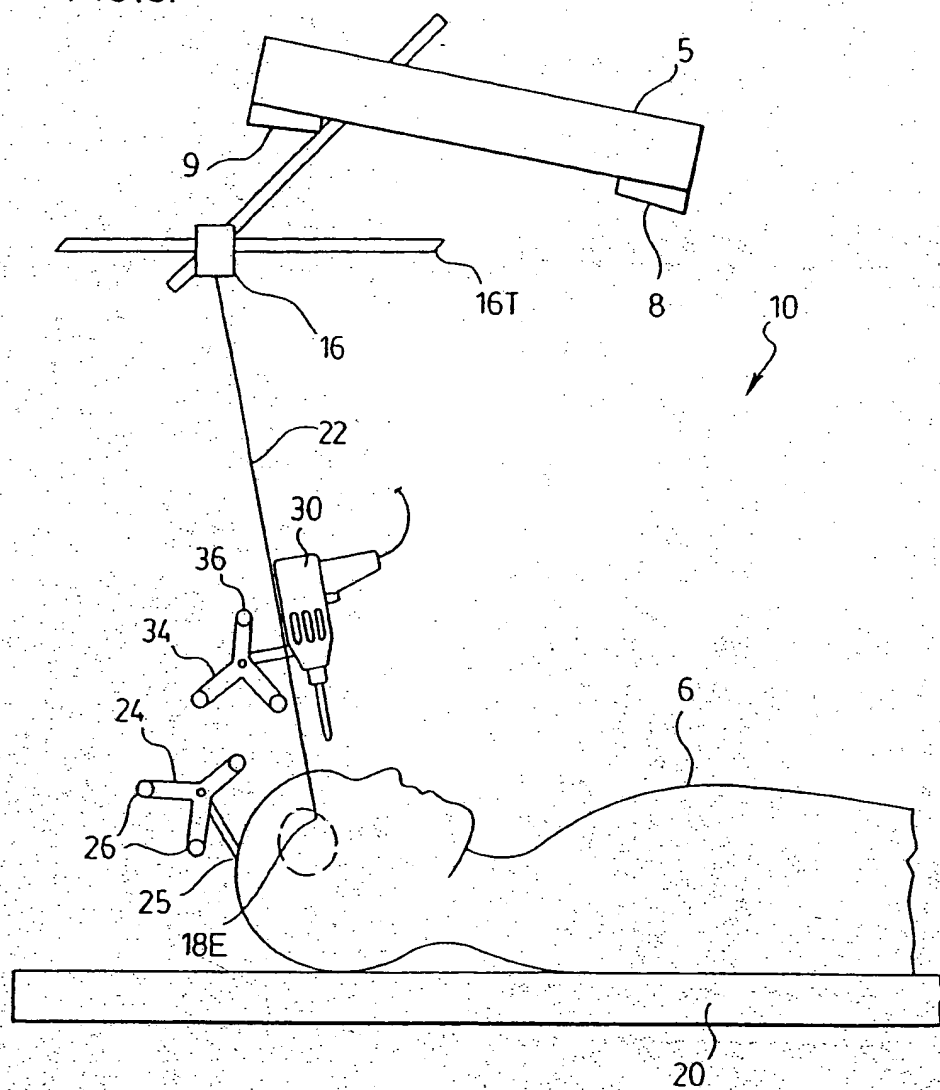
FIG. 2



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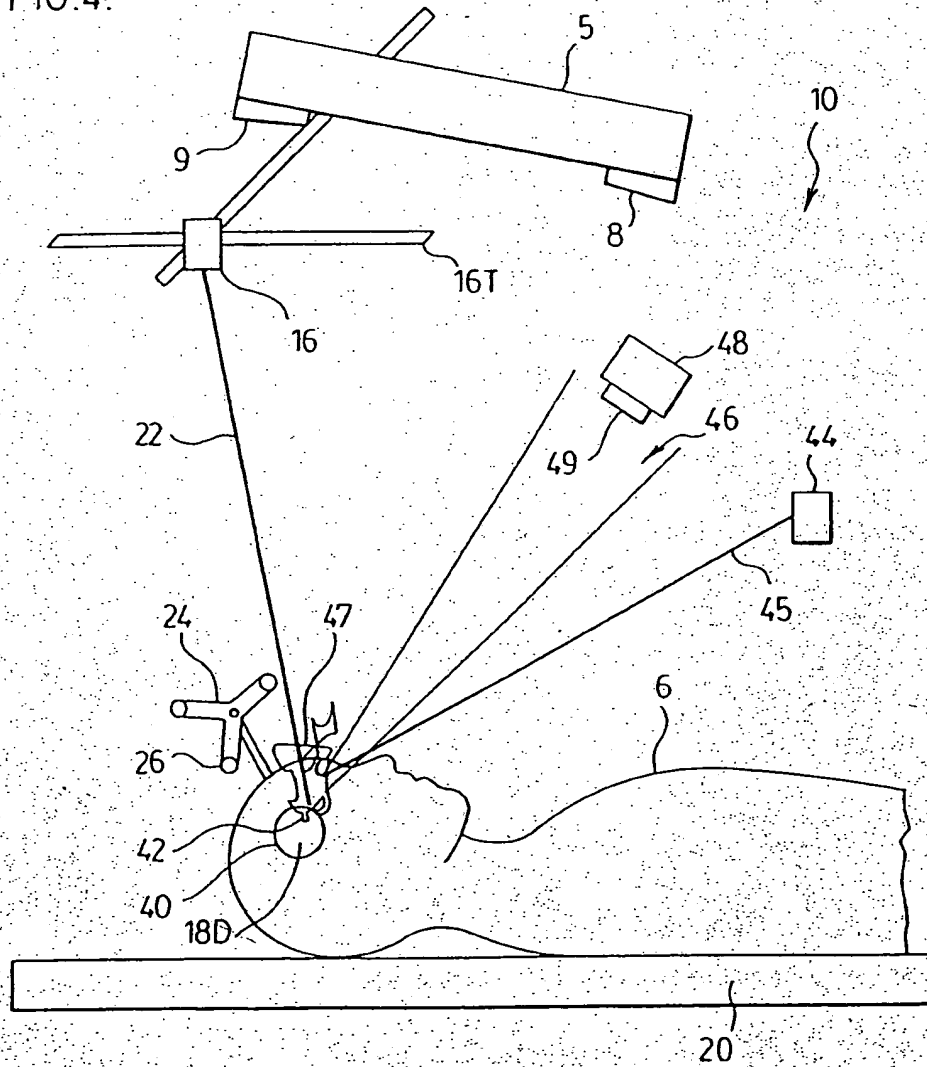
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FIG. 3.



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FIG. 4.



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INTERNATIONAL SEARCH REPORT

International Application No.

PCT/CA 00/01054

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 A61B19/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 715 836 A (LUNDT BERND ET AL) 10 February 1998 (1998-02-10)	1,11-15, 18,21-23 5,6,8,10
Y	abstract column 2, line 29 - line 46 column 4, line 40 - column 6, line 6; figure 1	
X	US 5 772 593 A (HAKAMATA KAZUO) 30 June 1998 (1998-06-30)	1,9, 11-15, 18,19, 21-23 10
Y	column 2, line 59 - column 6, line 4	3,4,19, 20
A	column 6, line 1 - line 4; figures 1-3	
	— / —	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents

A document defining the general state of the art which is not considered to be of particular relevance

E earlier document (but published on or after the international filing date)

L document which may throw doubts on priority claims or which is cited to establish the publication date of another citation or other special reason (as specified)

O document referring to an oral disclosure, use, exhibition or other means

P document published prior to the international filing date but later than the priority date claimed

T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

X document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

Y document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

Z document member of the same patent family

Date of the actual completion of the international search

25 April 2001

Date of mailing of the international search report

03.05.01

Name and mailing address of the ISA

European Patent Office, P.B. 5018 Patentbus 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 600 NL
Fax: (+31-70) 340-3015

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INTERNATIONAL SEARCH REPORT

Intern. Application No.
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C. (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	EP 0 402 250 A (UNIV MIAMI) 12 December 1990 (1990-12-12) column 7, line 22 - line 42	2, 16, 17
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A	US 4 610 806 A (ROSEN GERALD M) 9 September 1986 (1986-09-09) abstract; figure 1	3, 4, 19, 20
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA 00/01054

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☒ No protest accompanied the payment of additional search fees.

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INTERNATIONAL SEARCH REPORT

International Application No. PCT/CA 00 01054

FURTHER INFORMATION CONTINUED FROM PCT/SA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1, 2, 11-18, 21-23

System and method for projecting markings onto an anatomical body whereby the markings are permanently marked.

2. Claims: 1, 3, 4, 15, 19, 20

System and method for projecting markings onto an anatomical body whereby the markings are temporarily marked

3. Claims: 1, 5-10

System for projecting markings onto an anatomical body whereby the spatial determinator comprises an optical tracking system and further comprising radiation detection means

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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PCT/CA 00/01054

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